

Delta Differential One-way Ranging (DDOR) Transmitter Onboard Mars Orbiter Mission (MOM)

Chitra Ramamurthy, Rahul Karkara, Deepali C. Vaishya, Jolie R.
Communication Systems Group
ISRO Satellite Centre
Bangalore, India
chitra@isac.gov.in

Abstract—Delta Differential One-way ranging (DDOR) is an interferometer technique used in deep space missions to calculate the angular position of a satellite with reference to a well known source which is usually a quasar.

A Transmitter has been used in Mars Orbiter Mission (MOM) for DDOR measurement to improve the accuracy of orbit determined by other techniques. The Transmitter operates at S-band with carrier phase modulated by a single tone at around 4 MHz approximately.

This paper discusses the principle of DDOR measurement, how the specifications for the Transmitter were arrived at, the design & realization using the available components and its on-orbit performance.

Keywords—Differential one-way ranging, Phase Modulation, Phase locked Loops, Transmitter

I. INTRODUCTION

Most of the Low Earth Orbit satellites of Indian Space Research Organization (ISRO) use sequential tone ranging technique and Global Positioning System (GPS) Receivers for orbit determination, while some use only GPS Receivers. In Chandrayaan-1 mission, Doppler information was used for more accurate determination of the orbit.

Mars Orbiter Mission (MOM), being a deep space mission, required additional technique to improve the accuracy of the orbit determined by Sequential tone Ranging and Doppler measurements. Thus, the concept of Delta Differential One-way Ranging (DDOR) was introduced for the first time in ISRO's

mission. An exclusive Transmitter was designed and developed to fulfill this requirement.

Section II of this paper discusses the basic principle of DDOR technique, Section III regarding how the specifications of DDOR Transmitter were arrived at, Section IV the configuration, block diagram and the explanation of the Transmitter, Section V the environmental tests carried out on the Transmitter and Section VI the on-orbit performance.

II. PRINCIPLE OF DDOR TECHNIQUE

DDOR technique is based on the well-known principle of Very Large Baseline Interferometer (VLBI) and hence requires two stations, which are very well separated, forming a baseline. This is a one way measurement meaning only transmission from spacecraft is required. It is differential range measurement since only the difference in the range of the spacecraft to the ground stations is measured and not the absolute range. The concept is explained in the following paragraph with reference to Fig. 1 below.

The radio signal from the satellite arrives at the ground station antennas as rays which can be approximated as parallel. The imaginary line B connecting the antennas is called the base line which passes through the Earth because these are located in different continents. Another imaginary line is drawn which is at 90° to the received rays.

The path length difference is calculated as follows: The signal received at each station is recorded using an open loop receiver. The signals are digitized, filtered, converted into a standard format and then transmitted to a common location. These

signals are processed by a correlator which gives the difference in the time delay, τ , which is the difference in the time of arrival of the rays at the two ground stations due to the signals taking different paths. Multiplying it with the velocity of light, c , gives the range difference.

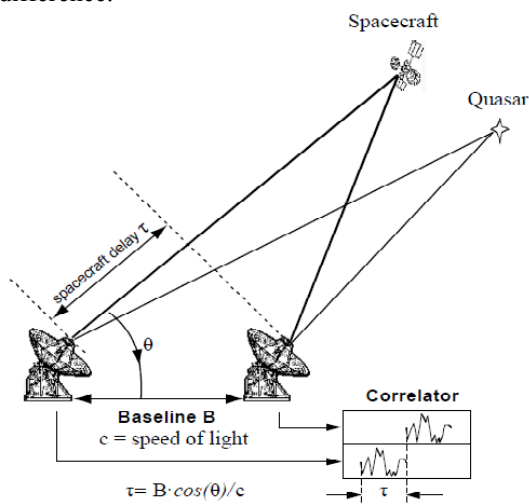


Fig. 1. Configuration of DDOR System

The angular position of the spacecraft in the sky is refined using the calculated range difference and the knowledge of the baseline orientation.

Plain DOR measurement explained above gives knowledge about the angular position of the satellite in the plane containing the baseline and the satellite. But, a number of errors, some of which are due to offset in station clocks, group delays experienced in the ground station instruments and effects of media, have to be taken care of to get the desired accuracy.

To overcome the above mentioned effects, the following method is used. A reference source which is angularly close to the spacecraft, the angular separation not being more than 10° , is chosen. This is usually a quasar and a DOR measurement is carried out on this source. The ground station antennas are then pointed to the satellite and another DOR measurement is done. The antennas are again pointed to the reference source to check the calibration. When the individual DOR results are differenced, the errors mentioned in the previous paragraph are removed and the technique becomes accurate for deep space orbit determination purpose. This technique is known as Delta Differential One-way Ranging.

Two baselines with orthogonal components are required for getting right ascension and declination coordinates of the angular position of the satellite. Since ISRO has only one Deep Space Station, it was not possible to make DDOR measurements with its own stations. Jet Propulsion Laboratory's (JPL) Deep Space Network was used for MOM. The two baselines used were Goldstone- Canberra and Goldstone-Madrid.

III. SPECIFICATIONS OF THE DDOR TRANSMITTER

The specifications of the DDOR Transmitter were derived from CCSDS recommendation 401.0-B, Section No. 2.5.6B. DDOR Transmitter was planned as a standalone unit, with the configuration arrived at, using the available components at the centre. The specifications of the Transmitter and how they meet the CCSDS recommendations are given in Table I.

TABLE I.

Specifications	How they meet CCSDS /MOM requirement
Carrier frequency : 2296.36375 MHz	S-band has been chosen for communicating with MOM. Accordingly, carrier frequency has been chosen to fall within the allocated deep space band of 2290 to 2300 MHz
Tone frequency: 3.89875 MHz	As per CCSDS recommendation, only one tone at a frequency of $4 \text{ MHz} \pm 10\%$ is used at S-band.
Power output: $10 \text{ dBm} \pm 1 \text{ dB}$	As per CCSDS recommendation, signal power to noise density ratio should be at least 1 dB-Hz for tone and greater than 13 dB-Hz for carrier, if carrier phase is used to aid in tracking DOR tone. Using this DDOR Transmitter, carrier-aided tracking can be done since carrier and tone are coherent with each other by virtue of being derived from the same TCXO. With DDOR Transmitter power level of 10 dBm and the TWTA power output of about 42 dBm , the expected carrier CNDR is 29 dB-Hz and tone SNDR is 23.5 dB-Hz for modulation index of 0.7 rad and Ground Station G/T of 36 dB/K for a distance of 220 million km.

Modulation index: 0.7 rad $\pm$ 0.1 rad	As per CCSDS recommendation, carrier suppression due to modulation by tone can go up to 1.1 dB. This corresponds to modulation index of 0.7 rad.
Allan deviation of the oscillators used is 5×10^{-11} and 7×10^{-11} .	As per CCSDS recommendation, Allan deviation of the onboard oscillator should be better than 4×10^{-10} at 2 GHz integrated over 1 sec duration.

IV. CONFIGURATION AND DESCRIPTION

The configuration of the DDOR system is shown in Fig. 2.

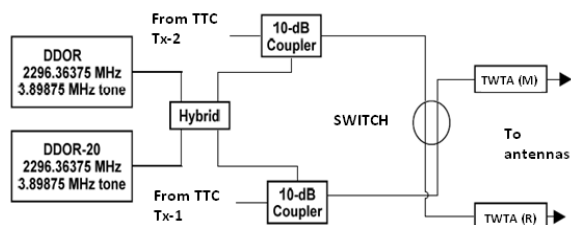


Fig. 2. Configuration of DDOR System

The configuration for DDOR transmission system consists of main and redundant DOR transmitters in cold redundancy, both operating at the same frequency. The outputs of the main and redundant DOR transmitters are fed to the two inputs of the 3-dB hybrid coupler. One output of the 3-dB coupler is fed to the coupled port of the 10-dB coupler whose main port is fed from TTC Transmitter-1. The output of this coupler is connected to the coaxial transfer switch, whose output, when position-1 is selected, goes to TWTA (main). Similarly, the other output of 3-dB coupler is combined with that of TTC Transmitter-2 and connected to the switch, when in position 2, connected to TWTA (redundant). Thus, the output of either main DDOR or redundant DOR transmitter gets connected to either TWTA (main) or TWTA (redundant) along with the output of either TTC Transmitter-1 or -2. The outputs of TWTAs are connected to antennas.

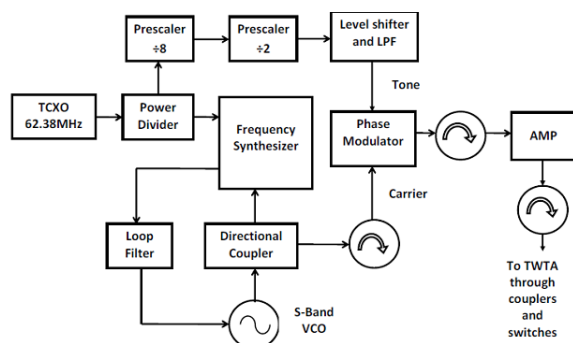


Fig. 3. Block Diagram of DDOR Transmitter

Fig.3 shows the block diagram of the Transmitter. The TCXO at 62.38 MHz is the basic source from which both the downlink carrier at 2296.36375 MHz

and the tone at 3.89875 MHz have been derived. The output of the TCXO is fed to a 3 dB power divider. One output of the power divider is used to derive the tone and is fed to the prescalers $\div 8$ followed by $\div 2$.

The output of the $\div 2$ prescaler is level shifted to suit the bias requirement of varactor diodes in phase modulator and filtered by a LPF with a rejection of about 30 dB at 8 MHz and is fed to the Phase modulator.

The other output of the power divider acts as the reference for the PLL frequency synthesizer. The main input of the synthesizer is fed from the coupled port of the directional coupler whose input is from a VCO at S-band. The VCO is locked to the TCXO by PLL technique with the loop filter being external to the synthesizer.

The main port output of the directional coupler serves as the carrier and is fed to the Phase Modulator. The Phase Modulator phase modulates the carrier by the DOR tone. The output of the Phase Modulator is amplified to the required level of 10 dBm by an amplifier stage.

The photograph of the DDOR Transmitter is shown in Fig.4.

V. ENVIRONMENTAL TESTS

The main DDOR Transmitter was subjected to the environmental testsgiven in Table II:

The redundant Transmitter had undergone proto-Flight model test conditions with higher level of vibration and 5 degrees extended temperature tests.



Fig. 4. Photograph of DDOR Transmitter

Sl no	Tests	Test levels
1	Initial Bench test	Ambient conditions
2	Hot and Cold soak test	1 cycle, 6 hrs dwell @ -15oC & +55oC
3	Step test in temperature	1 cycle, 6 hrs dwell @ -15oC & +55oC in steps of 5°C with dwell time of 30 mins.
4	Active thermal cycling test (Pre-Vibration)	6 cycles ½ hr dwell followed by 1 cycle 6 hrs dwell @ -15oC & +55oC
5	Active Vibration test	Random : Acceptance level in all three axes
6	Thermovacuum cycling test (Post Vibration)	3 cycles 2 hr dwell followed by 1 cycle 24 hrs dwell @ -15oC & +55oC, vacuum 10-5torr& Cold start at -30oC
7	RF Burn-in test	168 hrs @+50°C
8	Final Bench test	Ambient conditions

TABLE II.

VI. ON-ORBIT PERFORMANCE

During Geo centric orbit, the Delta DOR Transmitters were switched ON and transmission was made through TWTA (redundant) and Medium Gain Antenna and TWTA (main) and High Gain Antenna in November 2013. The RF spectrum, modulation index and received signal CNDR were as expected.

But, actual measurements were carried out only in heliocentric orbit since the spacecraft should be visible from two ground stations simultaneously. The first Delta Differential one-way Range measurement was carried out on the following days with the two baselines as mentioned below:

1. Day 358 of 2013 using Goldstone- Madrid.
2. Day 1 of 2014 using Goldstone- Canberra.

After the above passes, the measurements have been carried out at least 50 times, with increasing frequency as MOM approached Mars. Onboard performance evaluation can be summarized as below:

- Random error on a QSQ (Quasar- Spacecraft- Quasar) point is 0.4 nsec. Average of 3 QSQ points over a pass has an accuracy of 0.23 nsec.
- Carrier transmit frequency has been stable to ± 1 kHz at 2296368750 Hz.

- Received signal power at level as expected from prelaunch link analysis.
- Short term 1-way carrier stability as expected, and adequate for DOR measurement.

These DDOR measurements were incorporated into the orbit information obtained by Doppler observation method, which improved the accuracy and was very helpful in Mars Orbit Insertion.

CONCLUSION

A Transmitter was designed and developed for use onboard Mars Orbiter Mission for performing Delta Differential one-way range measurements. It performed excellently in orbit and served its purpose of improving the accuracy of the orbit for Mars orbit insertion.

ACKNOWLEDGEMENT

We sincerely thank Mr. Yateendra Mehta, Group Director, Communication Systems Group, Mr. Ranganath Ekkundi, Deputy Director, Communication and Power Area, Dr. S.K. Shiva Kumar, Director, ISRO Satellite Centre for their guidance and constant encouragement. We would also like to thank our ex-colleagues Mrs. V.

Parimalavalli and Mr. Sourabh Basu for their design contributions.

REFERENCES

- [1]. DSMS Telecommunications Link Design Handbook
“210 Delta Differential One-way Ranging” Released July 15.
2004.
- [2]. Recommendations for Space Data System standards
“Radio frequency and Modulation systems”-Part 1 Earth
stations and spacecraft. Recommended standard CCSDS
401.0-B.
- [3]. “Deep Space Telecommunication Systems Engineering”
by Yuen Joseph H ed.
- [4]. “Radiometric Tracking Technique for Deep Space
Navigation” by Catherine L. Thornton and James S Border.